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Effect of rubber crumb and polyethylene terephthalate as coarse aggregate in self-compacting concrete

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ABSTRACT

The need to recycle materials such as rubber and plastics has become more vital than before due to the volume of waste generated by these materials. In this study, the mutual effect of using Rubber Crumb (RC) and Polyethylene Terephthalate (PET) as coarse aggregates in Self-Compacting Concrete (SCC) was investigated. Varying percentages of RC and PET (10, 20 and 30 %) as replacements for granite were incorporated in SCC with a designed target compressive strength of 20 N/mm^2 and tested for its slump flow, slump height, flowability, density, and compressive strength. The results reveal that the slump flow, slump height and flowability of the fresh concrete for all the percentage inclusion of RC and PET falls within the recommended limit by the European Federation of National Associations Representing for Concrete (EFNARC). The density of the concrete reduced as the inclusion of RC and PET increased up to 20 % then it began to increase. The compressive strength of the SCC declined as the percentage inclusion of PET and RC increased. However, the inclusion of 10 % PET and RC gave a compressive strength of 16.3 N/mm^2 which could be considered for mass concrete production.
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1. Introduction

Aggregates are significant constituents in the production of concrete since they constitute the bulk of the weight of any concrete sample. This, certainly, has resulted in the increasing and continuous demand for the natural materials used in producing concrete. Similar to the demand for the utilization of natural resources emerges an increasing concern for preserving natural resources such as aggregates and the environment by using recycled or discarded materials termed as waste [1]. The discarding of waste rubbers and plastics is expensive and continuously increases the number of landfills, generating significant pressure on the local authorities who need to deal with the pollution which results from the disposal of these wastes [2]. The sustainable management of these rubber and plastic is a huge task for the industries and public sectors because they serve as breeding habitats for rodents and mosquitoes when stockpiled [3]. Burning them results in air pollution which is a health risk.

The global use of rubber and polyethylene terephthalate has reached 3.2 billion units [4]. This implies that these wastes will take ample space in landfills and serve as soil pollutants. Various methods have been adopted in making good use of waste rubber and polyethylene terephthalate. These include shredding before disposal. However, the huge operating cost makes this method impractical [3]. Another option is to recycle them in concrete [5,6]. Haridharan et al. [7] investigated the effect of waste tire crumb rubber on the mechanical strength of concrete. Their findings reveal that the inclusion of the rubber reduced the compressive strength and modulus of elasticity of the concrete. However, it only reduced the flexural strength of concrete when its quantity was beyond 15 % inclusion. Nwankwo and Wilson [2] recommended that the addition of rubber crumbs as a partial replacement for coarse aggregate could be useful for up to 10 %. Beyond that percentage, the strength of concrete would be negatively impacted. Rahman et al. [8] considered the effects of combining Polyethylene Terephthalate (PET) and Rubber Crumb (RC) as fine aggregate in normal concrete. The fine aggregate was replaced with up to 30 % of the waste. They recommended that PET could replace sand up to 20 % while 10 % RC could be used to replace sand

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in the same concrete sample. Ola and Mohammed [9] also used PET and Rubber Crumb RC in Asphaltic concrete and concluded that both materials had no negative impact on the concrete.

Self-Compacting Concrete is an innovative concrete that flows under its weight even in the presence of congested reinforcements without segregation [10]. SCC is economically beneficial because it results in faster construction, produces better surface finishes, reduces on-site manpower, and has no requirement for vibration. SCC requires smaller volume and reduced sizes of coarse aggregates when compared with normal Vibrated Concrete (VC), and this contributes in no small measure to its mechanical properties [11].

Though several researchers have worked on the properties of concrete containing PET and RC, the properties of SCC containing both PET and RC in varying percentages have not been reported. Therefore, this study helps to bridge this gap.

2. Materials and methods

The materials used in this study include potable water with a pH of 6.7 conforming to ASTM C1602/C1602M-22 [12], Portland Limestone Cement (PLC) of grade 42.5 conforming to BS EN 413–1: 2011 [13] and NIS 444–1:2003 [14], naturally occurring river sands and granite dust as fine aggregates, crushed granite stones, PET, RC and superplasticizer. Mix design (cement – 450 kg/m^3, granite dust – 135 kg/m^3, sand – 960 kg/m^3, crushed granite – 813 kg/m^3, superplasticizer – 1.5 L/100 kg of cement at 0.50 water-cement ratio) for grade 20 N/mm^2 SCC as specified by Akinpelu et al. [10] was adopted. Coarse aggregate was partially replaced with 10 % PET and 10 % RC; 20 % PET and 20 % RC and 30 % PET and 30 % RC respectively. The fresh concrete was tested for slump flow, slump height, flowability, passing ability and segregation resistance using a slump cone and V-funnel apparatus as specified by EFNARC [15]. The V-Funnel, slump height and slump flow are shown in Figs. 1 – 3 respectively.

The mix proportions adopted for this study are shown in Table 1. The hardened concrete was tested for its density and compressive strength at 28 days. A total of thirty – six (36) cube specimens of 150 mm × 150 mm × 150 mm dimensions were evaluated. The samples were cured by water immersion and tested after 7, 14 and 28 days respectively using a compression testing machine of 1500 kN capacity. The reported strength is the average of three specimens for the corresponding days respectively.



Fig. 1. V-Funnel test.



Fig. 2. Slump height.

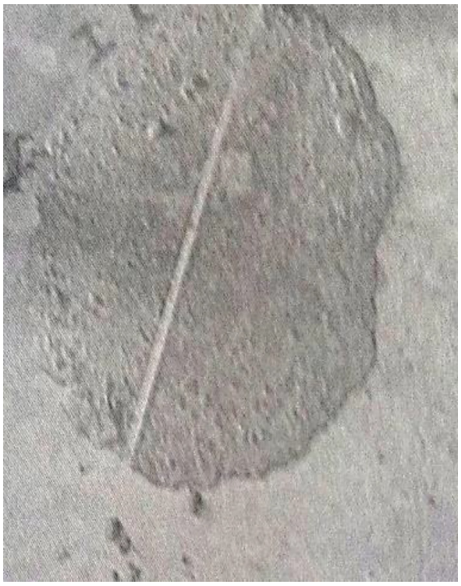


Fig. 3. Slump flow.

3. Results and discussion

3.1. Fresh properties of SCC with varying percentages of PET and RC

The test findings on the fresh SCC are presented in Figs. 4 - 6. Fig. 4 shows the slump flow for the SCC containing varying percentages of RC and PET. The values range from 630 to 720. All the samples except that of the control mix (0 % RC and PET) produced slump heights which are within the values of 650 – 800 for slump height for SCC recommended by EFNARC [15].

Fig. 5 shows the slump height for the SCC containing varying percentages of PET and RC. The values range from 20 to 130. All the samples except that of the control mix (0 % RC and PET) pro-

Table 1
Mix Proportion per cubic meter of SCC.

Mix	Cement (kg)	Dust (kg)	Sand (kg)	Granite (kg)	RC (kg)	PET (kg)	Superplasticizer (Litres)	W/C
0 % PET & 0 % RC	450	135	960	813	0	0	6.75	0.50
10 % PET &10 % RC	450	135	960	650.4	81.3	81.3	6.75	0.50
20 % PET & 20 % RC	450	135	960	487.8	162.6	162.6	6.75	0.50
30 % PET & 30 % RC	450	135	960	325.2	243.9	243.9	6.75	0.50

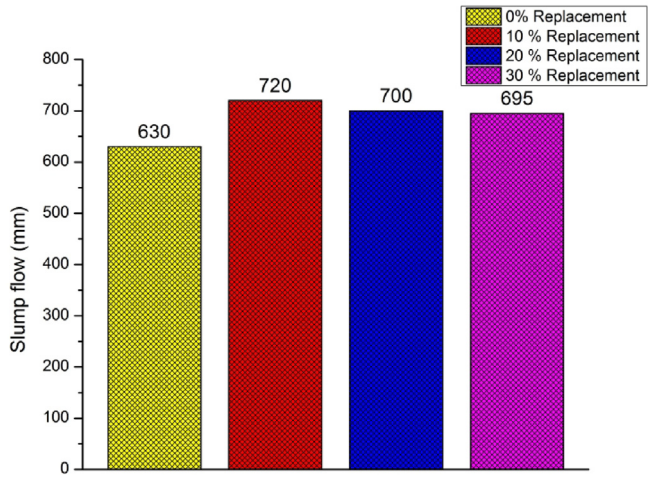


Fig. 4. Slump flow of fresh SCC.

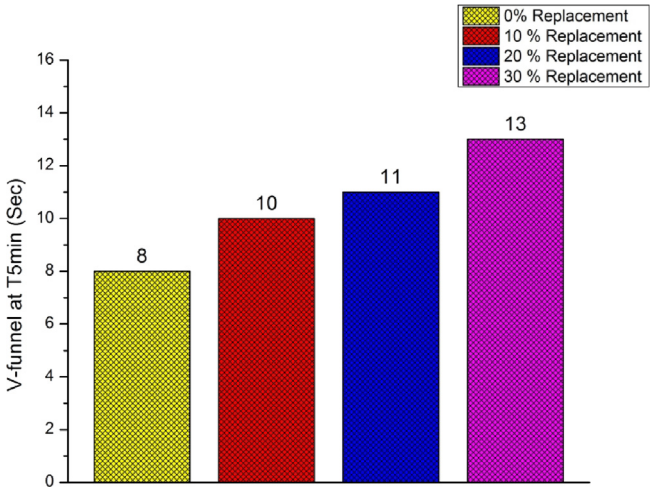


Fig. 6. Flowability of fresh SCC.

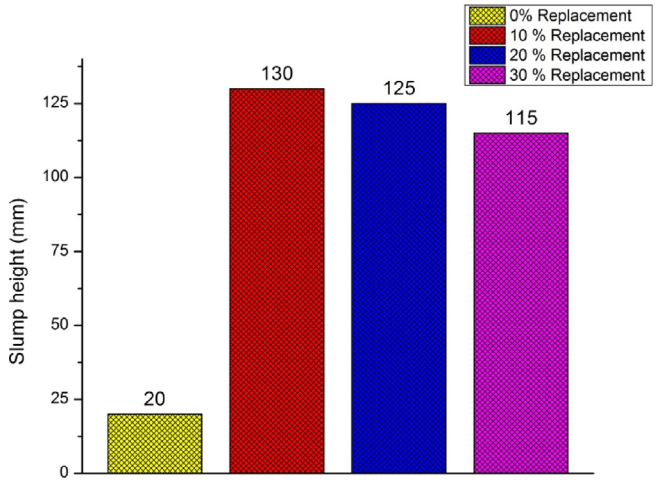


Fig. 5. Slump height of fresh SCC.

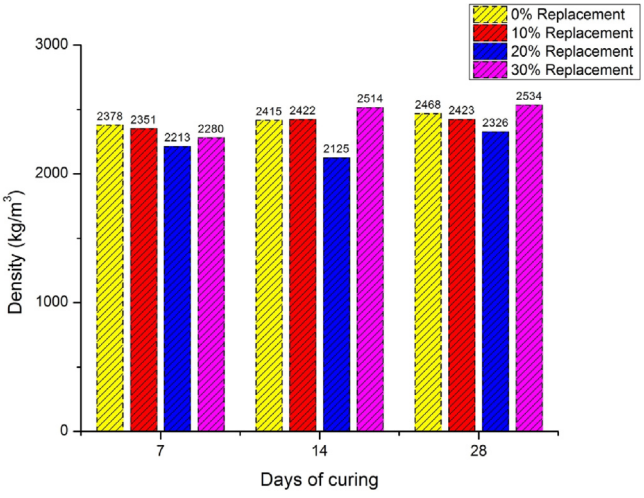


Fig. 7. Density of hardened SCC.

duced slump heights which are within the values of 100 – 175 for slump height for SCC recommended by EFNARC [15].

Fig. 6 shows the V-funnel at T_{5min} (flowability) for the SCC containing varying percentages of RC and PET. The values range from 8 to 13. All the samples produced flowability which is within the values of 6 – 15 for flowability for SCC recommended by EFNARC (EFNARC, 2002).

3.2. Properties of hardened SCC with varying percentages of PET and RC

Fig. 7 (densities of the SCC) shows that the mixes had closely related densities and the densities increased as the curing age increased. Though the variation in density does not follow a regular pattern, 30 % inclusion of RC and PET gave the highest density at 28 days of curing. However, 10 % and 20 % inclusion of RC and PET produced SCC with lower densities. The reduction in density will help to reduce the dead load on concrete structures.Fig. 8..

Fig. 8. shows the compressive strengths of the tested SCC. The targeted compressive strength of 20 N/mm^2 for SCC was attained at 28 days by the control mix containing 0 % RC and PET. However, the inclusion of PET and RC reduced the compressive strength of the SCC for all the curing days considered in the study. 10 % inclusion of PET and RC gave a compressive strength of 16.3 N/mm^2 which, though not recommended for reinforced concrete, could be considered for mass concrete production [16]. The fact that the concrete samples containing 10 % inclusion of PET and RC had a greater compressive strength compared with the other concrete samples with higher percentages of PET and RC could be attributed to their containing more percentage of granite and les-

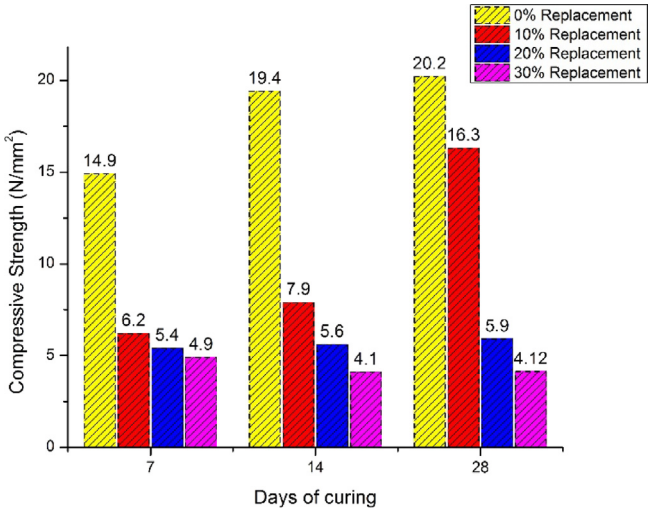


Fig. 8. Compressive strength of hardened SCC.

ser percentages of PET and RC. This is in line with the findings of Rahman et al. [8].

4. Conclusions

This study sets out to investigate the performance of combining RC and PET as a partial replacement for granite in SCC. Fresh and hardened properties of the concrete were tested and compared with EFNARC recommendation and the control samples. The following conclusions were drawn from the study:

i. Slump flow for 10 – 30 % inclusion of RC and PET falls within the recommended values by EFNARC for SCC.
ii. Slump height for 10 – 30 % inclusion of RC and PET falls within the recommended values by EFNARC for SCC.
iii. The flowability of all the samples falls within the recommended values by EFNARC for SCC.
iv. The addition of PET and RC reduces the density of SCC by up to 20 % inclusion. However, a 30 % inclusion of RC and PET increased the density of SCC.
v. There was a reduction in the strength of SCC with the introduction of RC and PET. 10 % inclusion of RC and PET gave the highest strength of 16.3 N/mm^2 for the combinations. This strength is only suitable for mass concrete production.

Data availability

The data used are included in the manuscript.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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